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Manual of Phosphoric Acid Fuel Cell Power Plant Cost Model and Computer Program

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Cleveland State University

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Prepared for
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Morgantown, West Virginia 26505
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INTRODUCTION

Cost model of phosphoric acid fuel cell powerplant includes two parts: a method for estimation of fuel cell system capital costs, and an economic analysis which determines the levelized annual cost of operating the system used in the capital cost program.

Cost estimates are prepared for a given powerplant based on the equipment specifications discussed in the previous report of the performance model. Costs were estimated by determining the actual capacities of the equipment and the existing cost data. Current costs of these equipments in the form expected to be used were obtained from the references. Total module cost can be obtained by multiplying the equipment cost by the Direct Cost Factor (DCF), Indirect Cost Factor (ICF), and Contingency Factor (CF).

The levelized annual cost of an investment is defined as the minimum constant net revenue required each year of the life of the project to cover all expenses, the cost of money, and the recovery of the initial investment. This is the capital investment analysis approach commonly used by electric utilities.

The cost model has been coded in Fortran programs with several input options. Mathematical formulation and program description will be discussed in this report. A sample problem will be presented to express the inputs and outputs.

I. SYSTEM DESCRIPTION

As shown in Figure 1, methane which is circulated by compressor (C) is preheated by heat exchanger E-1 prior to mixing it with the super heated steam which receives its heat by passing through heat exchanger E-9. Before entering the reformer, the methane steam mixture is heated via heat exchangers E-2 and E-3. Inside the reformer, methane is catalytically reformed by reaction with excess steam to produce carbon monoxide, carbon dioxide, and the desired product, hydrogen. The effluent from the reformer is cooled by flowing through heat exchanger E-2 before it enters the high temperature shift converter S-1. The function of the high temperature shift converter is to increase the hydrogen concentration and to reduce the carbon monoxide concentration of the reformer gas effluent. The temperature of the effluent from the shift converter S-1 is then reduced by passing through heat excangers E-1, E-9 and E-6 before entering the low temperature shift converter S-2. The low temperature shift converter further increases the hydrogen concentration by promoting the shift reaction at a lower operating temperature. The effluent from the low temperature shift converter then enters the fuel cell containing H_2, CO, CH_4, CO_2 and H_2O. The fuel cell converts inputs of hydrogen and oxygen to DC power, water and heat. Oxygen is delivered to the fuel cell by air compressor A, which also provides air to the reformer burner. The spent fuel from the fuel cell anode goes to the burner after mixing with air supplied by compressor A.

Before entering the burner, the mixture is preheated by the burner effluent via heat exchanger E-4. The spent fuel is then burned with whatever additional methane is needed to provide the thermal energy necessary for the reformer reaction.

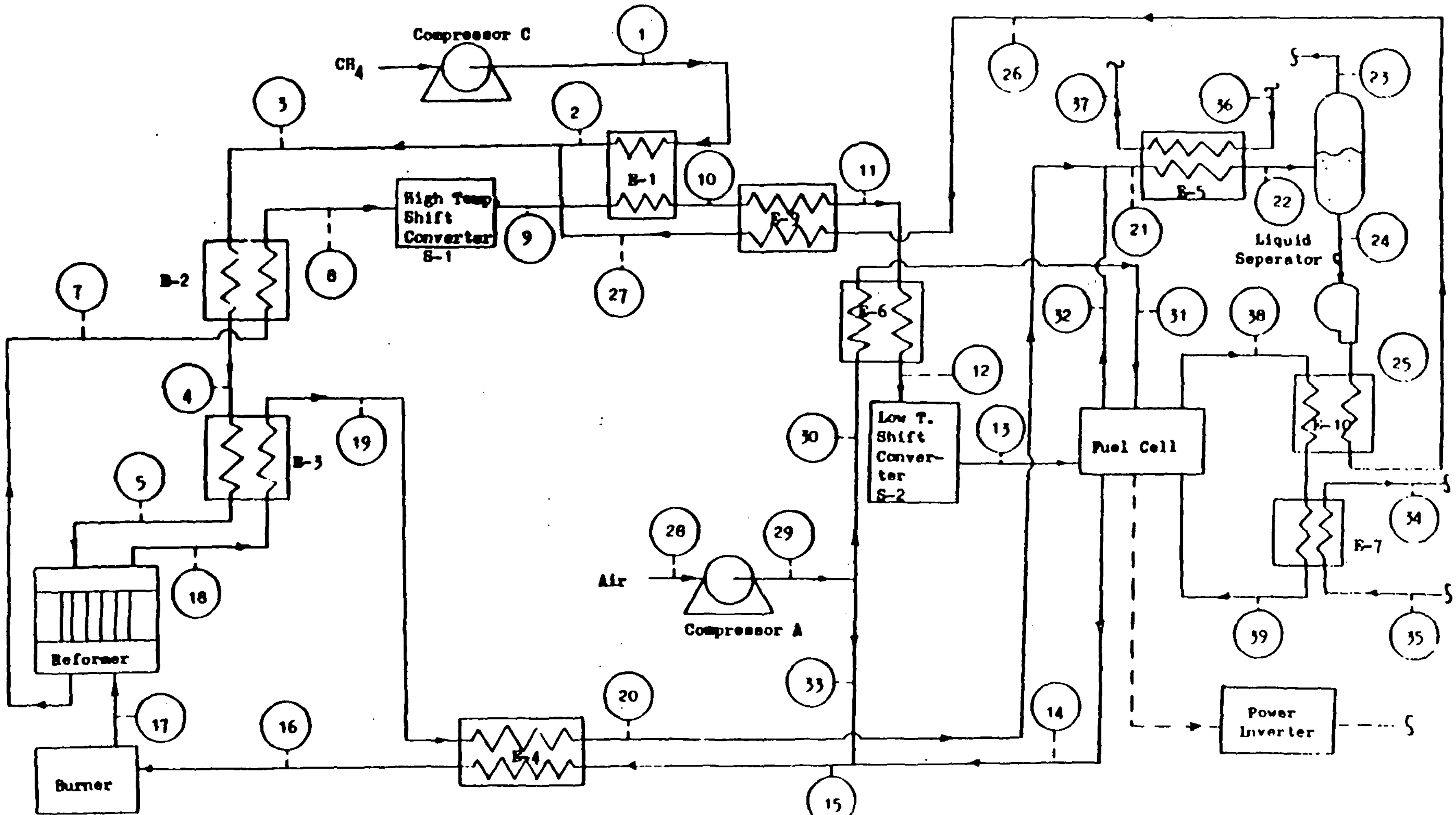


Figure 1 Flow diagram of CSU designed PAFC system

Heat generated in the fuel cell is removed by heat exchangers E-7 and E-10. Heat from heat exchanger E-7 can then be utilized in industrial heat processing or space heating and cooling, while exchanger E-10 is used to preheat the water supplied by liquid separator Q to provide the necessary steam needed for the reforming process. The effluents from the burner and fuel cell cathode will have their water removed and separated by condenser E-5 and liquid separator Q before allowing them to be exhausted to the atmosphere.

II. COST MATHEMATICAL MODEL

2.1 Capital Investment

Total module cost of a piece of equipment can be separated into two parts: FOB equipment cost and the working capital costs; the latter is related to the former. The relationship of total module cost and FOB equipment cost is shown in Figure 2, where the total module cost is obtained by multiplying the purchased equipment cost (FOB) by three factors: Direct Cost Factor (DCF), Indirect Cost Factor (ICF), and Contingency Factor (CF). The definitions of these are also shown in the figure. DCF and ICF of each equipment can be obtained from Refs. 3 and 4, where CF is the input option. The working capital cost is the difference of these two kinds of cost.

All the costs were corrected by the Marshall and Swift cost index to be in constant mid-1981 dollars which is basic year used in the model.

Equipment Cost

There are several methods for estimating equipment cost. Three of them were used in the developed model for different components, which are power factor method, interpolation of true cost data, and unit-cost estimate. The fuel cell stack cost was estimated by unit-cost estimate method. For pumps and power inverter, linear interpolation was used to estimate the cost from tabulated data published by Exxon (Ref. 1). The power factor method was most used for the estimation of equipment cost in this model, which includes the reformer, the shift converters, the heat exchangers, the separator, and the compressors.

Figure 2

GENERALIZED INVESTMENT COST ESTIMATING LOGIC (REF. 3)

FOB Equipment	$\boxed{100}$	
Material Factor	xxx	x.xx Direct Cost Factor (DCF) [Piping, Concrete, Steel, Instruments, Electrical, Insulation, Paint, & Labor]
Labor Factor	xx	
Direct M&L Cost	$\boxed{xxx}$	
Engineering	xx	
Construction Overhead	xx	x.xx Indirect Cost Factor (ICF)
Bare Module Cost	$\boxed{xxx}$	
Contingency, etc.	xx	
Fee	x	x.xx Contingency Factor (CF)
Total Module Cost	$\boxed{xxx}$	= 100 x DCF x ICF x CF

Briefly, the power factor method is

$$\frac{C}{S} = a_1 S^{a_2} + a_3 \tag{1}$$

where C = cost

S = capacity

a_1, a_2, and a_3 are coefficients to be determined

$$\text{From (1)} \quad \ln\left(\frac{C}{S} - a_3\right) = \ln a_1 + a_2 \ln S \tag{2}$$

A linear regression on sample cost data will provide the values of a_1, a_2, and a_3. Cost data have been obtained from the sources listed in the references.

The linear interpolation algorithm is

$$Y = YT(I-1) + [YT(I)-YT(I-1)]\ [X-XT(I-1)]/[XT(I)-XT(I-1)] \tag{3}$$

where Y is the cost of X capacity

YT(I) is the listing cost of XT(I) listing capacity.

The stack cost estimates were based on calculations of actual quantities of raw materials used to fabricate the components (unit-cost estimate). Current cost of raw materials, in the form expected to be used, were obtained from Chemical Marketing Report (Ref. 10) and Refs. 1 and 2. Fabrication costs were then determined by multiplying the material cost by a manufacturing cost factor, which was selected based on the production rate and the degree of automation envisioned for the manufacturing facility. The factor reflects manufacturing value added, including direct and supervisory labor plus other manufacturing burdens (e.g., maintenance and inventory costs). For example, the cost of catalyst (platinum) is

$$CCP = (CPLxLCPxAAxNCELLxNS)\ x\ (1 + MCP) \tag{4}$$

Energy Related (E): purchased power and fuel

Non-Energy Related (NE): other variables and semi-variables

Fixed Charges: depreciation, return-on-investment; income taxes, and local taxes and insurance.

Those cost elements were first converted into a series of future cash flows (escalation allowed) which were then levelized to obtain a uniform annual cost series. This procedure is presented graphically in Figure 3.

Levelized annual costs were determined from the following generalized relationship:

$$LAC = IxFCR+E\left[\sum_{n=1}^{N}\frac{(1+i+e_E)^n}{(1+\gamma)^n}\right]CRF_\gamma + NE\left[\sum_{n=1}^{N}\frac{(1+i+e_{NE})^n}{(1+\gamma)^n}\right]CRF_\gamma \qquad (5)$$

where FCR = fixed charge rate, and equal to

$$\frac{CRF_{m,\,n_B}}{(1-t)}\left[1-t\,(DEP)-C\right] \qquad (6)$$

and $CRF_{m,\,n_B}$: capital recovery factor for the after-tax cost of capital m and the economic life n_B

t: tax rate

C: investment tax credit rate

DEP: levelized depreciation factor (Sum of Years Digit) and

$$\text{equal to } \frac{z\left[n_T - 1/CRF_{m,\,n_T}\right]}{n_T\,(n_T+1)^m} \qquad (7)$$

n_T: tax depreciation life

m: after tax cost of capital at the assumed inflation rate

I : total module cost in mid-1981 dollars, and equal to KmKeK $(1+e_k + i_o)^{N*-No-L} + W$

and Km: cost-of-capital factor = $e^{0.418mL}$

L : design and construction time

Ke: escalation factor = $e^{0.562(e_k + io)L}$

K : equipment cost

W : working capital

e_k: real capital cost escalation per year

N*: first year of commercial operation of the investment

No: the year used as basis for the cost estimate k

i_o: annual inflation rate

E : annual energy cost

NE : annual non-energy cost

eE : annual energy escalation

eNE : annual non-energy escalation

γ : weighted cost of capital with inflation io

n : project life

CRFr: capital recovery factor at γ cost of capital and n years, which equal to

$$\frac{(1+\gamma)^n - 1}{\gamma(1+\gamma)^n} \tag{8}$$

where CPL : cost of platinum, \$/g

LCP : loading of platinum, δ/cm^2

AA : active area per cell, cm^2

NCELL: number of cells per stack

NS : number of stacks

MCP : manufacturing factor for catalyst.

The manufacturing cost factors used for estimating the cost of PAFC stack in this model were adopted from Ref. 1. More detailed description of this factor can be found in Ref. 4, pages 191-201.

2.2 Levelized Annual Cost Analysis

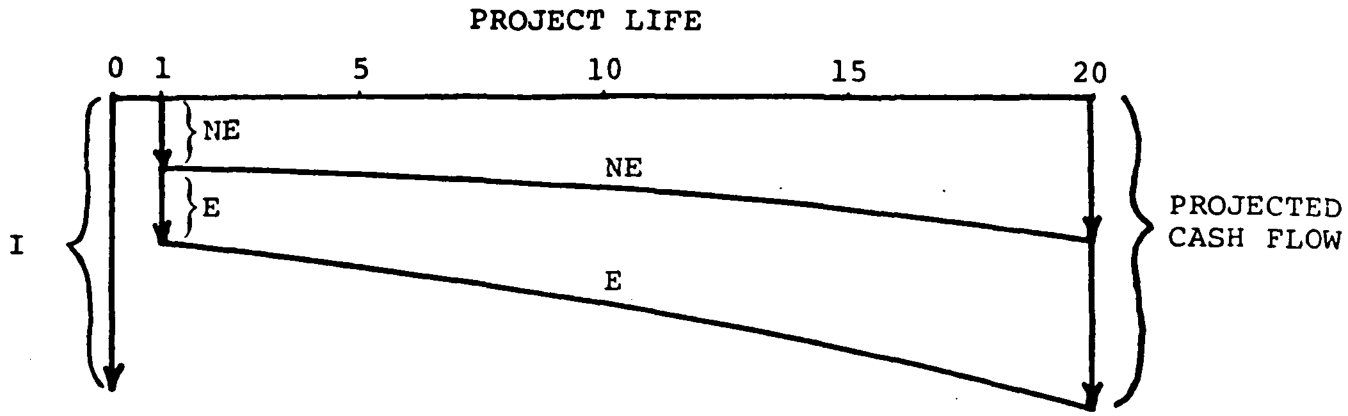
The levelized annual cost (LAC) of an investment is defined as the minimum constant net revenue required each year of the life of the project to cover all expenses, the cost of money, and the recovery of the initial investment. LAC is a comparative measure of both the fixed and variable costs associated with the investment, incurred at different times throughout the life of the project.

The following formulations were taken principally from: NASA Documents dated April 1, 1979. Groundrules for Economic Analysis which also used in the study "Study of Component Technologies for Fuel Cell On-Site Integrated Energy Systems", NASA CR-165152 (December 1980), prepared by A. D. Little, Inc., for NASA Lewis Research Center.

The computation of the levelized annual cost was accomplished by segregating annual costs into three categories, namely, energy related costs, non-energy related costs and fixed charges. The cost items grouped in each category were as follows:

Figure 3

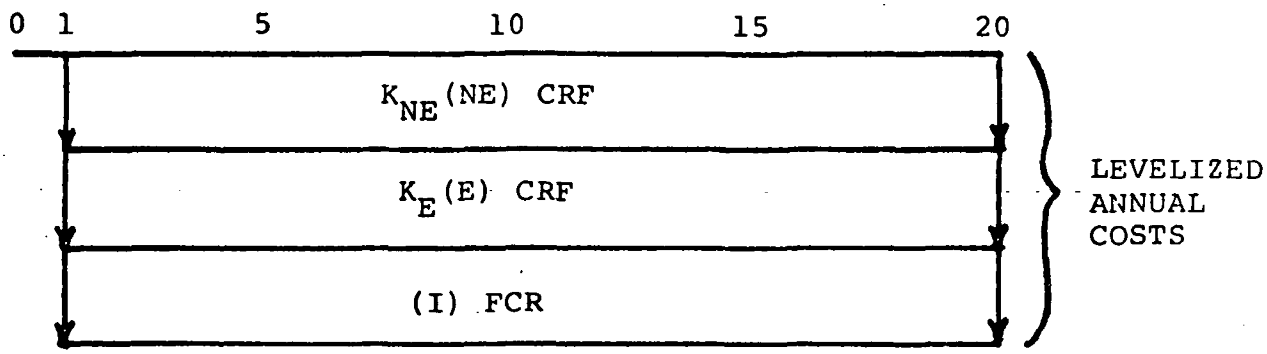
APPROACH TO LEVELIZED ANNUAL COST ANALYSIS



I = Capital Investment

NE = Non-energy Cost

E = Energy Cost



K = Conversion Factor Defined as $\left[\sum_{n=1}^{20} \frac{(1+i+e)^n}{(1+r)^n}\right]$

where: i = inflation
e = real escalation
n = year
r = weighted cost of capital

FCR = Fixed Charge Rate with SYD depreciation and 10% tax credit

III. COST COMPUTER MODEL

3.1 Program

There is one subroutine (RLIN) in addition to the BLOCK DATA and MAIN programs in the cost computer model. The MAIN program estimates the capital investment of the PAFC powerplant, and calculates the levelized annual cost using the algorithm described in the previous chapter. The subroutine RLIN do the linear interpolation with two sets of input serial data and a specific capacity. The BLOCK DATA supplies the cost data tables, for the pump and the power inverter, from Ref. 1, and also the physical properties of the gases in the system. Table 1 shows the nomenclature of the variables.

3.2 Program Operation

The program input consists of a set of NAMELIST data which must be in a specified order. The first NAMELIST set is called INDEX and contains the Marshall and Swift cost index of the specified time. All the indices are obtained from Chemical Engineering magazine.

The second set (CONST) has the constants used in the power factor method (Section 2.1). The general form used here is

$$C = a_1 \, (S/a_2)^{a3} \tag{9}$$

where C is cost and S is capacity. The definitions of the constants for the equipment in this NAMELIST are listed in Table 2.

The third set (FUCEC) contains the amount, the unit cost, and the manufacturing cost factor of the material used in manufacturing the PAFC stack.

TABLE 1

NOMENCLATURE OF COST COMPUTER MODEL

Equipment Number and Unit for Estimating the Cost

1	fuel cell stack	kW
2	reformer	MBtu/hr ejected
3	fuel compressor	brake HP
4	heat exchanger	transfer area ft^2
5	separator	g-mole water
6	pump	W
7	condenser	gal/min water
8	high temperature shift converter	g-mole H2
9	low temperature shift converter	g-mole H2
10	power inverter	V
11	air compressor	ft^3/min

Cost of Fuel Cell Stack

AA: active area per cell, cm^2
NS: number of stacks
SV: operating voltage, V
CPL: cost of platinum, $/g
CMRIN: Chemical Marketing Reporter index of raw material
NCELL: number of cells per stack
LCP: platinum loading, g/cm^2
LESL: electrolyte support layers loading, g/cm^2
LEM: electrolyte matrix loading, g/cm^2
LBP: bipolar plate loading, g/cm^2
CKW: capacity of fuel cell stack, kW
MCP: mfg. cost factor of catalyst
MESL: mfg. cost factor of electrolyte support layers
MEM: mfg. cost factor of electrolyte matrix
MBP: mfg. cost factor of bipolar plate
MCC: mfg. cost factor of cooling cartridge
MSH: mfg. cost of factor of stack hardware
CCP: cost of platinum (catalyst)
CGFP: cost of electrolyte support layers - graphite fiber paper
CEM: cost of electrolyte matrix - silicon carbide fiber
CBP: cost of bipolar plate - carbon/phenolic resin
CCC: cost of cooling cartridge - carbon plate with copper tube grid
CSH: cost of stock hardware - end plates, manifolding, tie rods
CGF: unit cost of graphite fiber paper, $/g
CSC: unit cost of silicon carbide fiber, $/g
CCPR: unit cost of carbon/phenolic resin, $/g
CMROT: CMR index of data year

TABLE 1 (cont'd)

NOMENCLATURE OF COST COMPUTER MODEL

Cost of Other Equipments

CC1:	power conditioner voltage, V
CC2:	power conditioner cost, $/kW
CP1:	pump power, W
CP2:	pump cost, $
HCH4:	high heating value of methane, Cal/g-mole
HCO:	high heating value of carbon monoxide, Cal/g-mole
HH2:	high heating value of hydrogen, Cal/g-mole
COST(I):	cost of equipment I, $
CEQ(I,J):	capacity of equipment I number J
IN81:	Marshall and Swift index of mid-1981
IN80:	Marshall and Swift index of 1980
IN79:	Marshall and Swift index of 1979
IN791:	Marshall and Swift index of January 1979
IN77:	Marshall and Swift index of 1977
IN75:	Marshall and Swift index of 1975
IN68:	Marshall and Swift index of 1968
IN67M:	Marshall and Swift index of mid-1967
CH4:	methane input, g-mole/hr
CO:	carbon monoxide input, g-mole/hr
H2:	hydrogen input, g-mole/hr
COMP:	brake hp of compressor, hp
HE(J):	transfer area of heat exchanger number J, m^2
SEPR:	amount of steam input in separator, g-mole/hr
PUM:	power of pump, hp
COND:	inlet H_2O flow rate of condenser
HSHIF:	inlet hydrogen flow rate of high temp. shift converter, g-mole/hr
LSHIF:	inlet hydrogen flow rate of low temp. shift converter, g-mole/hr
AIRC:	inlet air flow rate, g-mole/hr

Total Module Cost and Operation Cost

DCF(I):	direct cost factor of equipment I
ICF(I):	indirect cost factor equipment I
CF:	contingency factor of equipment
CMAIN:	maintenance cost of fuel cell system, $/kWh DC
CREPL:	factor of capital cost for replacement
MTIME:	times which replacement will occur for 20 years usage
WATER:	cooling water input, g-mole/hr
CWAT:	cost of cooling water, $\$/m^3$
AVER:	mean factor of cooling water for recycle
ENPU:	input fuel flow rate, g-mole/hr
AVHT:	average heating value of input fuel, Btu/ft^3
CENG:	cost of energy fuel, $/GJ

TABLE 1 (cont'd)

NOMENCLATURE OF COST COMPUTER MODEL

Levelized Annual Analysis

CC:	cost of common equity
CD:	cost of debt
CP:	cost of preffered equity
EK:	real capital cost escalation per year; i.e., rate of capital cost
ESC:	escalation, decimal
FC:	ratio of common equity
FD:	ratio of debt capital to total capital
FL:	annual inflation rate
FP:	ratio of preferred equity
L:	design and construction time, year
NE:	economic life
NSTAR:	first full year of commercial operation of investment change above or below the rate of inflation
NT:	tax depreciation life
NZERO:	the year used as basic year
TAX:	tax rate
TAXL:	state and local tax
TC:	investment tax credit rate
CAKE:	escalation factor
CAKM:	cost-of-capital factor
CAPIT:	capital investment
CEN:	levelized energy cost
CN:	non-energy cost
CRFRE:	capital recovery factor at R for economic life
CRFRK:	capital recovery factor at AK for energy in economic life
CRFRT:	capital recovery factor at R for tax depreciation life
DEP:	levelized depreciation factor for sum of years digits (SYD)
FCL:	levelized fixed charges
FCR:	fixed charge rate
R:	after tax cost of capital
RLAC:	levelized annual cost
TLIN:	levelized local tax and insurance

The fourth set (INPUTS) consists of the input flow composition of fuel compressor, condenser, separator, high temperature and low temperature shift converters, the transfer area of each heat exchanger, and power needed in compressor and pump.

The fifth set (FACTR) contains direct cost factor, indirect cost factor, and contingency factor of each equipment.

The sixth and seventh sets (NENEG and ENG) include the amount and unit cost of fuel and utilities used in the system. The maintenance information is in NENEG.

The last NAMELIST set (ECON) contains all the necessary data used for LAC analysis.

All of the input variables are listed in Table 3, along with their units and numerical values in the sample run.

3.3 Sample Problem

The computer code described in the previous sections was used to estimate the equipment capital cost and the levelized annual cost of CSU designed PAFC powerplant (Figure 1). A 100 kW powerplant was considered here, which included one fuel cell stack containing 200 cell plates with 1900 cm^2 active area in each cell plate. The middle of year 1981 was chosen as the basic year for constant dollar estimation.

TABLE 2

DEFINITIONS OF CONSTANTS IN NAMELIST CONST

Equipment	Constants Used in Equation 9 a_1	a_2	a_3
Reformer	C1	1	C2
Fuel Compressor	C3	1	C4
Heat Exchangers	C5	1	C6
Separator	C7	C8	C9
Pump	C10	1	C11
High Temperature Shift Converter	C12	C13	C14
Low Temperature Shift Converter	C15	C16	C17
Air Compressor	C18	1	C19

TABLE 3

INPUT DATA OF SAMPLE PROBLEM

NAMELIST Name	Variable Name	Sample Data	Unit	Definition
INDEX	IN81	696.9		M.& S. index of mid 1981
INDEX	IN80	659.6		M.& S. index of 1980
INDEX	IN791	561		M.& S. index of Jan. 1979
INDEX	IN77	505.4		M.& S. index of 1977
INDEX	IN75	444.3		M.& S. index of 1975
INDEX	IN68	273		M.& S. index of 1968
INDEX	IN67M	270		M.& S. index of mid 1967
CONST	C1....C19	7620,0.85,514.55,0.82,162.106,0.6934,1500, 817200,0.64,104.4,0.5,900.,4310,0.69,1320, 4540,0.69,7,0.68		constants listed in Table 2
FUCEC	AA	1900	cm^2	active area per cell
FUCEC	NS	4		number of stacks
FUCEC	SV	133	volt	operating voltage in the stack
FUCEC	CPL	16.75	$/g	cost of platinum(basic year)
FUCEC	CMRIN	158.34		CMR(Chemical Marketing Report) index of raw material of basic year
FUCEC	NCELL	200		number of cells per stack
FUCEC	LCP	0.00075	g/cm^2	loading of platinum
FUCEC	LESL	0.024	g/cm^2	loading of electrolyte support layers
FUCEC	LEM	0.039	g/cm^2	loading of electrolyte matrix
FUCEC	LBP	0.44	g/cm^2	loading of bipolar plate
FUCEC	CKW	100	KW	capacity of the fuel cell
FUCEC	MCP	0.05		mfg. cost factor of catalyst
FUCEC	MESL	0.6		mfg. cost factor of electrolyte support layers
FUCEC	MEM	0.6		mfg. cost factor of electrolyte matrix
FUCEC	MBP	1.5		mfg. cost factor of bipolar plate
FUCEC	MCC	1.5		mfg. cost factor of cooling plate
FUCEC	MSH	1.4		mfg. cost factor of stack hardware
FUCEC	CGF	0.066	$/g	unit cost of graphite fiber paper
FUCEC	CSC	0.0176	$/g	unit cost of silicon carbide fiber
FUCEC	CCPR	0.0009	$/g	unit cost of carbon/phenolic resin
FUCEC	CMROT	198.66		CMR index of data year

TABLE 3
INPUT DATA OF SAMPLE PROBLEM
continued

NAMELIST Name	Variable Name	Sample Data	Unit	Definition
INPUTS	CH4	172.6	g-mole/hr	methane input flow rate
INPUTS	CO	2.79	g-mole/hr	carbon monoxide flow rate
INPUTS	H2	867.63	g-mole/hr	hydrogen flow rate
INPUTS	COMP	1.62	hp	brake hp of compressor
INPUTS	HE(J)	0.3945,1.4024,1.5395,2.3735,1.4953,0.2,0.6418	m^2	transfer area of heat exchanger J
INPUTS	SEPR	6820.63	g-mole/hr	input H20 flow rate of separator
INPUTS	PUM	0.00226	hp	power of pump
INPUTS	COND	132960.37,51396	g-mole/hr	input H20 flow rate of condensers
INPUTS	HSHIF	3708.6	g-mole/hr	input H2 flow rate of high temperature shift converter
INPUTS	LSHIF	3925.62	g-mole/hr	input H2 flow rate of low temperature shift converter
INPUTS	AIRC	24524	g-mole/hr	inlet air flow rate
FACTR	DCF(I)	1.15,1.42,1.15,1.35,1.14,1.75,1.16,1.15,1.15,1.15 1.75		direct cost factor of equipment I
FACTR	ICF(I)	1.14,1.28,1.14,1.1407,1.15,1.45,1.5086,1.14,1.14 1.14,1.45		indirect cost factor of equipment I
FACTR	CF	0.2		contingency factor of equipments
NENEG	CMAIN	0.00065	\$/KW-h DC	maintenance cost of system
NENEG	CREPL	0.5		factor of capital cost for replacement
NENEG	MTIME	4		times which replacement will occur for 20 yrs.
NENEG	WATER	184356	g-mole/hr	cooling water flow rate
NENEG	CWAT	.001316	\$/m^3	cost of cooling water
NENEG	AVER	12		mean factor of cooling water for recycle
ENG	ENPU	1405.16	g-mole/hr	input fuel flow rate
ENG	AVHT	360242.6	Btu/ft^3	average heating value of input fuel
ENG	CENG	6.29	\$/GJ	cost of energy fuel
ECON	TAX	0.48		tax rate
ECON	TC	0.1		investment tax credit rate
ECON	ESC	0.024		escalation
ECON	CD	0.03		cost of debt
ECON	CP	0.09		cost of preferred equity

TABLE 3
INPUT DATA OF SAMPLE PROBLEM
continued

NAMELIST Name	Variable Name	Sample Data	Unit	Definition
ECON	CC	0.09		cost of common equity
ECON	FD	0.4		ratio of debt capital to total capital
ECON	FP	0		ratio of preferred equity
ECON	FC	0.6		ratio of common equity
ECON	TAXL	0.02		state and local tax
ECON	FL	0		annual inflation rate
ECON	NT	20		tax depreciation life
ECON	NE	20		economic life
ECON	L	1	year	design and construction time
ECON	EK	0		real capital cost escalation per year
ECON	NSTAR	1982		first full year of commercial operation
ECON	NZERO	1981		basic year

Figure 4

SAMPLE INPUT DATA

```
&INDEX IN81=696.9,IN80=659.6,IN791=561.,IN77=505.4,IN75=444.3,IN68=273.
,IN67M=270.,
&END
&CONST C1=7620.,C2=.85,C3=514.55,C4=.82,C5=162.106,C6=.6934,
C7=1500.,C8=817200.,C9=.64,C10=104.4,C11=.5,C12=900.
C13=4310.,C14=.69,C15=1320.,C16=4540.,C17=.69,C18=7.,C19=.68,
&END
&FUCEC AA=1900.,NS=4,SV=133.,CPL=16.75,CMRIN=158.34,NCELL=200,LCP=.00075
,LESL=0.024,LEM=0.039,LBP=0.44,CKW=100.,MCP=0.05,MESL=0.6,MEM=0.6,MBP=1.5
,MCC=1.5,MSH=1.4,CGF=0.066,CSC=0.0176,CCPR=0.0009,CMROT=198.66,
&END
&INPUTS CH4=172.6,CO=2.79,H2=867.63,COMP=1.62,
HE=0.3945,1.4024,1.5395,2.3735,1.4953,0.2,0.6418,SEPR=6820.63,PUM=0.00226,
COND=132960.37,51396.,HSHIF=3708.6,LSHIF=3925.62,AIRC=24524.,
&END
&FACTR DCF=1.15,1.42,1.15,1.35,1.14,1.75,1.16,1.15,1.15,1.15,1.75,
ICF=1.14,1.28,1.14,1.407,1.15,1.45,1.5086,1.14,1.14,1.14,1.45,CF=0.2,
&END
&NENEG CMAIN=0.00065,CREPL=0.5,MTIME=4,WATER=184356.,CWAT=0.0013157,AVER=12.,
&END
&ENG ENPU=1405.16,AVHT=360242.64,CENG=6.29,
&END
&ECON TAX=0.48,TC=0.1,ESC=0.024,CD=0.03,CP=0.09,CC=0.09,FD=0.4,FP=0.,FC=0.6
,TAXL=0.02,FL=0.,NT=20,NE=20,L=1,EK=0.,NSTAR=1982,NZERO=1981,
&END
```

Figure 5

SAMPLE COMPUTER RUN

```
&INDEX
IN81= 696.8999
IN80= 659.5999
IN791= 561.0
IN77= 505.3999
IN75= 444.2998
IN68= 273.0
IN67M= 270.0
&END
&CONST
C1= 7620.0
C2= 0.850
C3= 514.5498
C4= 0.820
C5= 162.1060
C6= 0.69340
C7= 1500.0
C8= 817200.0
C9= 0.640
C10= 104.40
C11= 0.50
C12= 900.0
C13= 4310.0
C14= 0.690
C15= 1320.0
C16= 4540.0
C17= 0.690
C18= 7.0
C19= 0.6799999
&END
&FUCEC
AA= 1900.0
NS= 4
SV= 133.0
CPL= 16.750
CMRIN= 158.340
NCELL= 200
LCP= 0.7499999E-03
LESL= 0.240E-01
LEM= 0.390E-01
LBP= 0.440
CKW= 100.0
MCP= 0.50E-01
MESL= 0.60
MEM= 0.60
MBP= 1.50
MCC= 1.50
MSH= 1.40
CGF= 0.6599998E-01
CSC= 0.1760E-01
CCPR= 0.8999999E-03
CMROT= 198.660
&END
&INPUTS
CH4= 172.60
CO= 2.790
H2= 867.6299
COMP= 1.620
HE= 0.39450, 1.402399, 1.539499, 2.37350, 1.495299, 0.20, 0.64180
```

Figure 5 (cont'd)

SAMPLE COMPUTER RUN

```
SEPR= 6820.629
PUM= 0.2260E-02
COND= 132960.3, 51396.0
HSHIF= 3708.60
LSHIF= 3925.620
AIRC= 24524.0
&END
&FACTR
ICF= 1.139999, 1.280, 1.139999, 1.4070, 1.150, 1.450, 1.508599, 3*1.139999
1.450
DCF= 1.150, 1.419999, 1.150, 1.349999, 1.139999, 1.750, 1.160, 3*1.150, 1.750
CF= 0.20
&END
&NENEG
CMAIN= 0.6499998E-03
CREPL= 0.50
MTIME= 4
WATER= 184356.0
CWAT= 0.131570E-02
AVER= 12.0
&END
&ENG
ENPU= 1405.160
AVHT= 360242.6
CENG= 6.290
&END

  COST ANALYSIS FOR 100KW FUEL CELL SYSTEM

MID-1981 MONEY
100% LOAD FACTOR

EQUIPMENT CAPITAL COST(F.O.B)   PERCENTAGE
COST( 1)=   0.28001E 05         44.80
COST( 2)=   0.85823E 04         13.73
COST( 3)=   0.19509E 04          3.12
COST( 4)=   0.76818E 04         12.29
COST( 5)=   0.96691E 02          0.15
COST( 6)=   0.52845E 03          0.85
COST( 7)=   0.14186E 04          2.27
COST( 8)=   0.11188E 04          1.79
COST( 9)=   0.16464E 04          2.63
COST(10)=   0.10533E 05         16.85
COST(11)=   0.93940E 03          1.50


TOTAL CAPITAL COST(F.O.B)  0.62497E 05
TOTAL WORKING CAPITAL COST  0.36873E 05
ANNUAL O&M   0.83828E 04
ANNUAL ENERGY COST INYEAR J=0  0.61490E 05


&ECON
TAX= 0.480
TC= 0.9999996E-01
ESC= 0.240E-01
CD= 0.30E-01
CP= 0.8999997E-01
CC= 0.8999997E-01
FD= 0.40
```

Figure 5 (cont'd)

SAMPLE COMPUTER RUN

```
FP= 0.0
FC= 0.60
TAXL= 0.20E-01
FL= 0.0
NT= 20
NE= 20
L= 1
EK= 0.0
NSTAR= 1982
NZERO= 1981
&END

INFORMATION OF ECONOMIC FACTOR:

 LEVELIZED DEPRECIATION FACTOR (SYD)     0.67699
 FIXED CHARGE RATE    0.09791
 CAPITAL RECOVERY FACTOR OF ECOMONIC LIFE     0.08718
 CAPITAL RECOVERY FACTOR OF TAX DEPRECIATION LIFE     0.08718


LEVELIZED FIXED CHARGES    0.98846E 04

LEVELIZED ENERGY COST    0.76084E 05


TOTAL LEVELIZED COST    0.97380E 05
```

The following are the summary of the results:

1. Equipment Capital Cost (FOB) - in mid-1981 money

Equipment	Cost (FOB)-$	Percentage of Total FOB
fuel cell module	28001	44.8
reformer	8582	13.7
fuel compressor	1951	3.1
heat exchangers	7682	12.3
separator	97	0.2
pump	528	0.9
condenser	1419	2.3
high temperature shift converter	1119	1.8
low temperature shift converter	1646	2.6
power inverter	10535	16.8
air compressor	939	1.5
total	62497	100.0

2. Total Working Cost

Total Working Cost = total module cost - total FOB cost (Figure 2)
36873 = 99370 - 62497

3. Levelized Annual Analysis

annual operation and maintenance	8383
levelized local tax and insurance	3028
levelized energy cost	76084
levelized fixed charges	9885
total levelized annual cost	97380

The required CPU time to run this sample problem is less than 0.01 minute on IBM/370.

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LISTING OF THE COST COMPUTER MODEL

```
C*************************************************************************
C  THIS PROGRAM IS TO CALCULATE GENERALIZED INVESTMENT COST ESTIMATING LOGIC  *
C  WHICH IS RECOMMENDED BY K. M. GUTHRIE, "PROCESS PLANT ESTIMATING,EVALUATION*
C  ,AND CONTROL"                                                              *
C*************************************************************************
      BLOCK DATA
      REAL CC1(20),CC2(20),CP1(20),CP2(20)
      COMMON/DATA/CC1,CC2,CP1,CP2,HCH4,HCO,HH2
C CC1: POWER CONDITION VOLT (VOLT)
C CC2: POWER CONDITION COST ($/KW)
C CP1: PUMP POWER (WATT)
C CP2: PUMP COST($)
C HCH4: HIGH HEAT VALUE OF CH4 (CAL/G-MOLE)
C HCO: HIGH HEATING VALUE OF CO (CAL/G-MOLE)
C HH2: HIGH HEATING VALUE OF H2 (CAL/G-MOLE)
      DATA CC1/50.,164.,203.,248.,304.,366.,433.,528.,657.,920.,1560./
      DATA CC1(12)/2810./,CC1(13)/1000000000./
      DATA CC2/200.,160.,150.,140.,130.,120.,110.,100.,90.,80,70.,60./
      DATA CC2(13)/50./
      DATA CP1/0.,61500.,264000.,615000./,CP2/500.,6700.,32000.,95400./
      DATA HCH4/212800./,HCO/67636./,HH2/68317./
      END
      REAL ICF(11),DCF(11),CEQ(20,10),COST(20),CC1(20),CC2(20),CP1(20)  -
     1,CP2(20),             LCP,LESL,LEM,LBP,MCP,MESL,MEM,MBP,MCC,MSH  -
     2,LSHIF,IN81,IN80,IN791,IN68,IN67M,IN77,IN75
      DIMENSION P(11),HE(7),COND(2)
      COMMON/DATA/ CC1,CC2,CP1,CP2,HCH4,HCO,HH2
      NAMELIST/FUCEC/ AA,NS,SV,CPL,CMRIN,NCELL,LCP,LESL,LEM,LBP,CKW     -
     1,MCP,MESL,MEM,MBP,MCC,MSH,CGF,CSC,CCPR,CMROT
      NAMELIST/INPUTS/ CH4,CO,H2,COMP,HE,SEPR,PUM,COND,HSHIF,LSHIF,AIRC
      NAMELIST/INDEX/ IN81,IN80,IN791,IN77,IN75,IN68,IN67M
      NAMELIST/FACTR/ ICF,DCF,CF
      NAMELIST/NENEG/ CMAIN,CREPL,MTIME,WATER,CWAT,AVER
      NAMELIST/ENG/ ENPU,AVHT,CENG
      NAMELIST/ECON/ TAX,TC,ESC,CD,CP,CC,FD,FP,FC,TAXL,FL,NT,NE,L,EK,   -
     1NSTAR,NZERO
      NAMELIST/CONST/ C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14,   -
     1C15,C16,C17,C18,C19
C
C**********************************************************************
C EQUIPMENT NO. AND UNIT FOR CALCULATING COST
C**********************************************************************
C  1: FUEL CELL, KW
C  2: REFORMER, MBTU/HR EJECTED
C  3: COMPRESSOR(GAS), BRAKE HP
C  4: HEAT EXCHANGER, TRANSFER AREA FT**2
C  5: SEPARATOR,G-MOLE H2O(L)
C  6: PUMP, WATTS
C  7: CONDENSER, GAL./MIN. H2O(L)
C  8: SHIFT CONVERTER(HIGH TEMPERATURE), MOLES H2
C  9: SHIFT CONVERTER(LOW TEMPERATURE), MOLES H2
C 10: POWER INVERTER, SYSTEM VOLT
C 11: AIR COMPRESSOR (BLOWER), FT**3/MIN.
C
```

```
C***********************************************************************
C DEFINITION:
C***********************************************************************
C COST(I): COST  OF EQUIPMENT I
C CEQ(I,J) : CAPACITY OF EQUIPMENT I NO.J (ACCORDING TO THE COST ESTIMAT
C
C
C***********************************************************************
C INPUT FUNCTIONS FOR CALCULATING COST OF EACH EQUIPMENT
C***********************************************************************
C
C BASIS:MID-1981 MONEY
C       100% LOAD FACTOR
C
      F2(S)=C1*(S)**C2*IN81/IN68
      F3(S)=C3*(S)**C4*IN81/IN68
      F4(S)=C5*S**C6*IN81/IN791
      F5(S)=C7*(S/C8)**C9*IN81/IN77
      F7(S)=C10*(S)**C11*IN81/IN67M
      F8(S)=C12*(S/C13)**C14*IN81/IN77
      F9(S)=C15*(S/C16)**C17*IN81/IN77
      F11(S)=C18*S**C19*IN81/IN68
C
C***********************************************************************
C READ IN THE MARSHALL AND SWIFT INDEX
C***********************************************************************
C IN81: INDEX OF MID 1981
C IN80: INDEX OF 1980
C IN79: INDEX OF 1979
C IN791: INDEX OF 1979 JAN.
C IN77: INDEX OF 1977
C IN75: INDEX OF 1975
C IN68: INDEX OF 1968
C IN67M: INDEX OF MID. 1967
C
      READ(5,INDEX)
      WRITE(6,INDEX)
      READ(5,CONST)
      WRITE(6,CONST)
C
C***********************************************************************
C CAL. THE COST OF FUEL CELL
C***********************************************************************
C
C INPUT:
C AA: ACTIVE AREA PER CELL (CM**2)
C NS: NUMBER OF STACKS
C SV: STACK VOLTAGE(VOLT)
C CPL: COST OF PLATINUM($/G) -- BASED ON BASIC YEAR
C CMRIN: CMR(CHEMICAL MARKETING REPORTER) INDEX OF RAW MATERITAL OF BASI
C NCELL: NUMBER OF CELLS PER STACK
C LCP: LOADING OF PLATINUM(G/CM**2)
C LESL: LOADING OF ELECTROLYTE SUPPORT LAYERS(G/CM**2)
C LEM: LOADING OF ELECTROLYTE MATRIX(G/CM**2)
```

```
C LBP: LOADING OF BIPOLAR PLATE(G/CM**2)
C CKW: CAPACITY OF THE FUEL CELL(KW)
C MCP: MFG. COST FACTOR OF CATALYST
C MESL:MFG. COST FACTOR OF ELECTROLYTE SUPPORT LAYERS
C MEM: MFG. COST FACTOR OF ELECTROLYTE MATRIX
C MBP: MFG. COST FACTOR OF BIPOLAR PLATE
C MCC: MFG. COST FACTOR OF COOLING CARTRIDGE
C MSH: MFG. COST FACTOR OF STACK HARDWARE
C CCP: COST OF CATALYST-- PLATTINUM
C CGFP: COST OF ELECTRODE SUPPORT LAYERS-- GRAPHITE FIBER PAPER
C CEM: COST OF ELECTROLYTE MATRIX-- SILICON CARBIDE FIBER
C CBP: COST OF BIPOLAR PLATE-- CARBON/PHENOLIC RESIN
C CCC: COST OF COOLING CARTRIDGE-- CARBON PLATE WITH COPPER TUBE GRID
C CSH: COST OF STACK HARDWARE-- END PLATES,MANIFOLDING,TIE RODS
C CGF: UNIT COST OF GRAPHITE FIBER PAPER,$/G
C CSC: UNIT COST OF SILICON CARBIDE FIBER,$/G
C CCPR: UNIT COST OF CARBON/PHENOLIC RESIN,$/G
C CMROT: CMR INDEX OF DATA YEAR
C
      READ(5,FUCEC)
      WRITE(6,FUCEC)
      CCP=(CPL*LCP*AA*NCELL*NS)*(1.+MCP)
      CGFP=(CGF*LESL*AA*NCELL*NS*CMRIN/CMROT)*(1.+MESL)
      CEM=(CSC*LEM*AA*NCELL*NS*CMRIN/CMROT)*(1.+MEM)
      CBP=(CCPR*LBP*AA*NCELL*NS*CMRIN/CMROT)*(1.+MBP)
C ASSUME THE RAW MATERITAL COST OF COOLING CARTRIDGE AND STACK HARDWARE
C IS THE SAME AS BIPOLAR PLATE
      CCC= CBP/(1.+MBP)*(1.+MCC)
      CSH=CBP/(1.+MBP)*(1.+MSH)
      COST(1)=CCP+CGFP+CEM+CBP+CCC+CSH
C
C*************************************************************************
C INPUT THE CAPACITY OF EACH EQUIPMENT AND CALCULATE THE COST
C*************************************************************************
C CH4: CH4 INPUT,G-MOLE/HR
C CO: CO INPUT,G-MOLE/HR
C H2: H2 INPUT,G-MOLE/HR
C COMP: BRAKE HP OF COMPRESSOR
C HE: TRANSFER AREA OF HEAT EXCHANGER,M**2
C SEPR: AMOUNT OF H2O INTO SEPARATOR,G-MOLE/HR
C PUM: POWER OF PUMP,HP
C COND: AMOUNT OF H2O INTO CONDENSER,G-MOLE/HR
C HSHIF: AMOUNT OF H2 INTO HIGH TEMP. SHIFT CONVERTER, G-MOLE/HR
C LSHIF: AMOUNT OF H2 INTO LOW TEMP. SHIFT CONVERTER, G-MOLE/HR
C AIRC: INLET AIR, G-MOLE/HR
C
      READ(5,INPUTS)
      WRITE(6,INPUTS)
      CEQ(2,1)=(CH4*HCH4+CO*HCO+H2*HH2)*3.97E-3/1.E+6
      COST(2)=F2(CEQ(2,1))
      CEQ(3,1)=COMP
      COST(3)=F3(CEQ(3,1))
      COST(4)=0.
      DO 1 K=1,7
```

```
      CEQ(4,K)=HE(K)/.3048**2
    1 COST(4)=COST(4)+F4(CEQ(4,K))
      CEQ(5,1)=SEPR
      COST(5)=F5(CEQ(5,1))
      CEQ(6,1)=PUM*745.7
      CALL RLIN(4,CP1,CP2,CEQ(6,1),COST(6))
      COST(6)=COST(6)*IN81/IN80
      CEQ(7,1)=COND(1)*18./1000./3.785/60.
      CEQ(7,2)=COND(2)*18./1000./3.785/60.
      COST(7)=F7(CEQ(7,1))+F7(CEQ(7,2))
      CEQ(8,1)=HSHIF
      COST(8)=F8(CEQ(8,1))
      CEQ(9,1)=LSHIF
      COST(9)=F9(CEQ(9,1))
      CEQ(10,1)=SV*NS
      CALL RLIN(13,CC1,CC2,CEQ(10,1),COST(10))
      COST(10)=(COST(10)*IN81/IN80)*CKW
      CEQ(11,1)=AIRC/453.6*10.73*298.*1.8/14.7/1.04/60.
      COST(11)=F11(CEQ(11,1))
      CAK=0.
      DO 2 K=1,11
    2 CAK=CAK+COST(K)
      DO 3 K=1,11
    3 P(K)=COST(K)/CAK*100.
C*****************************************************************
C INPUT DIRECT AND INDIRECT COST FACTORS
C*****************************************************************
C DCF(I): DIRECTOR COST FACTOR OF EQUIPMENT I
C ICF(I): INDIRECT COST FACTOR OF EQUIPMENT I
C CF    : CONTINGENCY FACTOR OF EQUIPMENT
      READ(5,FACTR)
      WRITE(6,FACTR)
      DO 4 K=1,11
    4 CAW=CAW+COST(K)*(DCF(K)*ICF(K)-1.)
      CAW=CAW*(CF+1.)
C*********************************(*******************************
C INPUT THE OPERATING AND MAINTENANCE COSTS (NONENERGY)
C*****************************************************************
C CMAIN: MAINTENANCE COST OF FUEL CELL, $/KWH DC OUTPUT
C CREPL: FACTOR OF CAPITAL COST FOR REPLANCEMENT
C MTIME: TIMES WHICH REPLACEMENT WILL OCCUR FOR 20 YRS USAGE
C WATER: INPUT COOLING WATER, G-MOLE/HR
C CWAT: COOLING WATER COST, $/M**3
C AVER: MEAN FACTOR OF COOLING WATER FOR RECYCLE
C
      READ (5,NENEG)
      WRITE (6,NENEG)
      OANDM=CKW*CMAIN*24.*365.+CAK*CREPL/MTIME+WATER
     1*18./1000000.*CWAT*24.*AVER
C*****************************************************************
C INPUT THE ENERGY COST THEN CAL. ENERGY OPERATING COST
C*****************************************************************
C ENPU: TOTAL INPUT FUEL, G-MOLE/HR
C AVHT: AVERAGE HEATING VALUE OF INPUT FUEL, BTU/FT**3
```

```
C CENG: COST OF ENERGY FUEL, $/GJ
C
      READ(5,ENG)
      WRITE(6,ENG)
      P0=ENPU/453.6*AVHT/1000000.*CENG*24.*365.
C WRITE THE RESULTS
      WRITE(6,103)
      WRITE(6,101) ((KK,COST(KK),P(KK)),KK=1,11)
      WRITE(6,102) CAK,CAW,OANDM,P0
C
C################################################################################
C PERFORM THE ECONOMIC CALCULATION AND A CASH FLOW ANALYSIS
C################################################################################
C
C********************************************************************************
C INPUT THE ECONOMIC ANALYSIS FACTOR
C********************************************************************************
C  TAX: TAX RATE
C  TC: INVESTMENT TAX CREDIT RATE
C  ESC: ESCALATION, DECIMAL
C  CD: COST OF DEBT
C  CP: COST OF PREFERRED EQUITY
C  CC: COST OF COMMON EQUITY
C  FD: RATIO OF DEBT CAPITAL TO TOTAL CAPITAL
C  FP: RATIO OF PREFERRED EQUITY
C  FC: RATIO OF COMMON EQUITY
C  TAXL: STATE AND LOCAL TAX
C  FL: ANNUAL INFLATION RATE
C  NT: TAX DEPRECITION LIFE
C  NE: ECOMONIC LIFE
C  L: DESIGN AND CONSTRUCTION TIME, IN YEAR
C  EK: REAL CAPITAL COST ESCALATION PER YEAR, I. E., THE RATE OF CAPITAL
C      CHANGE ABOVE OR BELOW THE RATE OF INFLATION
C  NSTAR: FIRST FULL YEAR OF COMMERCIAL OPERATION OF THE INVESTMENT
C  NZERO: THE YEAR USED AS BASIS FOR THE COST ESTIMATE
C
      READ(5,ECON)
      WRITE(6,ECON)
C  R: AFTER TAX COST OF CAPITAL
      R=(1.-(TAX+TAXL))*FD*CD+FP*CP+FC*CC+FL*(1.-(TAX+TAXL)*FD)
C  CAKM: COST-OF-CAPITAL FACTOR
      CAKM=EXP(.418*R*L)
C  CAKE: ESCALATION FACTOR
      CAKE=EXP(.562*(EK+FL)*L)
C  CAPIT: CAPITAL INVESTMENT
      CAPIT=CAKM*CAKE*CAK*(1.+EK+FL)**(NSTAR-NZERO-L)+CAW
C  TLIN: LEVELIZED LOCAL TAX AND INSURANCE
      TLIN=0.03*CAPIT
C  CN: NON-ENERGY COST
      CN=OANDM+TLIN
C  CRFRE: CAPITAL RECOVERY FACTOR AT R FOR ECOMONIC LIFE
      C3=1.
      C4=0.
      DO 5 I=1,NE
```

```
      C3=C3/(1.+R)
      C4=C4+C3
    5 CONTINUE
      CRFRE=1./C4
C  CRFRT: CAPITAL RECOVERY FACTOR AT R FOR TAX DEPRECIATION LIFE
      D1=1.
      D2=0.
      DO   6 I=1,NT
      D1=D1/(1.+R)
      D2=D2+D1
    6 CONTINUE
      CRFRT=1./D2
C
C*************************************************************************
C         CALCULATION ANNUAL COST OF ENERGY( VARY AT A CONST. ANNUAL RATE
C*************************************************************************
C CRFRK: CAPITAL RECOVERY FACTOR AT AK FOR ENERGY IN ECOMONIC LIFE
      AK= (1.+R)/(1.+ESC+FL)-1.
      G1=1.
      G2=0.
      DO 7 J=1,NE
      G1=G1/(1.+AK)
      G2=G2+G1
    7 CONTINUE
      CRFRK=1./G2
C  CEN: LEVELIZED ENERGY COST
      CEN=P0*CRFRE/CRFRK
C  DEP: LEVELIZED DEPRECIATION FACTOR FOR SUM OF YEARS DIGITS (SYD)
      DEP=2.*(NT-1./CRFRT)/(NT*(NT+1.)*R)
C  FCR: FIXED CHARGE RATE
      FCR=(CRFRE/(1.-(TAX+TAXL)))*(1.-(TAX+TAXL)*DEP-TC)
C  RLAC: LEVELIZED ANNUAL COST
      RLAC=CAPIT*FCR+CN+CEN
C  FCL: LEVELIZED FIXED CHARGES
      FCL=CAPIT*FCR
C*************************************************************************
C WRITE THE RESULTS
C*************************************************************************
      WRITE(6,104)
      WRITE(6,106) DEP,FCR,CRFRE,CRFRT
      WRITE(6,105) FCL,CEN,RLAC
C
  101 FORMAT(1X,'COST(',I2,')=',E13.5,10X,F5.2)
  102 FORMAT(//1X,'TOTAL CAPITAL COST(F.O.B)',E13.5/1X,'TOTAL WORKING CA-
     1PITAL COST',E13.5/1X,'ANNUAL O&M ',E13.5/1X,'ANNUAL ENERGY COST IN-
     2YEAR J=0',E13.5//)
  103 FORMAT(/'   COST ANALYSIS FOR 100KW FUEL CELL SYSTEM'//1X,'MID-198-
     11 MONEY'/1X,'100% LOAD FACTOR'//1X,'EQUIPMENT CAPITAL COST(F.O.B) -
     2  PERCENTAGE')
  104 FORMAT(/1X,'INFORMATION OF ECONOMIC FACTOR:'/)
  105 FORMAT(' LEVELIZED FIXED CHARGES ',E13.5//' LEVELIZED ENERGY COST -
     1',E13.5///' TOTAL LEVELIZED COST ',E13.5)
  106 FORMAT(1X,' LEVELIZED DEPRECIATION FACTOR (SYD) ',F10.5/              -
     1        1X,' FIXED CHARGE RATE ',F10.5/                              -
```

```
     2         1X,' CAPITAL RECOVERY FACTOR OF ECOMONIC LIFE ',F10.5/     -
     3         1X,' CAPITAL RECOVERY FACTOR OF TAX DEPRECIATION LIFE '    -
     4         ,F10.5//)
C
      STOP
      END
      SUBROUTINE RLIN(N,XT,YT,X,ANS)
C THIS SUBROUTINE IS TO CAL. LINEAR INTERPOLATION.
C THE ALGORITHM REQUIRES XT VECTOR TO BE IN ASCENDING ORDER......
      DIMENSION  XT(20),YT(20)
      I=2
      IF(X.LE.XT(1)) GO TO 20
      I=N
      IF(X.GE.XT(N)) GO TO 20
      DO 10 I=2,N
      IF(X.LE.XT(I)) GO TO 20
   10 CONTINUE
   20 ANS=YT(I-1)+(YT(I)-YT(I-1))/(XT(I)-XT(I-1))*(X-XT(I-1))
      RETURN
      END
```

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16. Abstract

Cost analysis of phosphoric acid fuel cell power plant includes two parts: a method for estimation of system capital costs, and an economic analysis which determines the levelized annual cost of operating the system used in the capital cost estimation. A FORTRAN computer program has been developed for this cost analysis.

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